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Comparison of EHL Film Thickness versus Temperature Characteristics of Mineral, PAO, and PAG Lubricants

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INTRODUCTION

The AGMA/AWEA Wind Turbine Committee is considering guidelines for rating bearing life in accordance with DIN 281 and the ASME Design Guide. These methods consider elastohydrodynamic (EHL) film thickness. Therefore, differences in EHL film thickness developed by wind turbine lubricants such as mineral, polyalphaolefin (PAO) and polyglycol (PAG) oils must be addressed to develop reliable guidelines.

OBJECTIVE

This study compares EHL film thickness versus temperature for mineral, PAO and PAG lubricants. The objective is to determine how lubricant choice may influence bearing life calculations.

SCOPE

Mineral, PAO and PAG lubricants are considered.

RATING STANDARDS

EHL film thickness was calculated using equations from AGMA 925 [1]. The film thickness equation is the Dowson and Toyoda equation for central film thickness. It applies to components with line contact such as gears and roller bearings.

LUBRICANT PARAMETERS

Table 1 shows values for absolute viscosity and pressure-viscosity coefficient obtained from AGMA 925 [1].

Table 1- Absolute viscosity and pressure-viscosity coefficient versus temperature

Temp.	Mineral		Synthetic PAO		Synthetic PAG	
°C	viscosity η_0 (cP)	press.-visc. coeff α (mm^2/N)	viscosity η_0 (cP)	press.-visc. coeff α (mm^2/N)	viscosity η_0 (cP)	press.-visc. coeff α (mm^2/N)
50	158.61090	0.020730	170.75820	0.013401	228.82	0.011041
60	94.98155	0.019346	110.41060	0.013108	164.62	0.010484
70	60.44313	0.018202	74.69445	0.012851	121.81	0.010000
80	40.49869	0.017246	52.54688	0.012623	92.42	0.009575
90	28.35234	0.016437	38.24137	0.012422	71.69	0.009200
100	20.60709	0.015745	28.66405	0.012241	56.71	0.008867

Figures 1 and 2 plot absolute viscosity and pressure-viscosity coefficient versus temperature.

TEMPERATURE

EHL film thickness is established by the temperature of the components. For gears, the temperature of the gear teeth is relevant, and for bearings, the temperature of the inner ring and rollers is relevant.

EHL FILM THICKNESS

EHL film thickness was calculated using equation 65 from AGMA 925 [1]:

$$Hc = 3.06\left(\frac{G^{0.56}U^{0.69}}{W^{0.10}}\right)\ldots\ldots(1)$$

where

Hc is the dimensionless central film thickness
G is the materials parameter
U is the speed parameter
W is the load parameter

If geometry, elastic properties, speed, and load are fixed, EHL film thickness varies with the pressure-viscosity coefficient (α) and absolute viscosity (η_0) as shown in equation (2):

$$Hc \propto \alpha^{0.56}\eta_0{}^{0.69}\ldots\ldots(2)$$

NORMALIZED EHL FILM THICKNESS

EHL film thickness was normalized by dividing equation (2) by properties for a mineral oil at 80°C as shown in equation (3):

$$Hc \propto \left(\frac{\alpha}{0.017246}\right)^{0.56}\left(\frac{\eta_0}{40.49869}\right)^{0.69}\ldots\ldots(3)$$

Table 2 and figure 3 summarize normalized film thickness calculated using equation (3).

Table 2- EHL film thickness normalized to mineral oil film thickness at 80°C

Temp. °C	Mineral	Synthetic PAO	Synthetic PAG
50	2.84345	2.34348	2.57309
60	1.92036	1.71324	1.99154
70	1.35868	1.29388	1.57558
80	1.00000	1.00496	1.27097
90	0.76114	0.79986	1.04306
100	0.59620	0.65022	0.86916

DISCUSSION

Figure 1 shows absolute viscosity versus temperature for mineral, PAO, and PAG lubricants. PAO lubricants have higher kinematic viscosity but lower density than mineral oils, whereas PAG lubricants have higher kinematic viscosity and higher density than mineral or PAO lubricants. Therefore, PAO lubricants have moderately higher absolute viscosity, and PAG lubricants have significantly higher absolute viscosity.

Figure 2 shows the curve for pressure-viscosity coefficient for mineral oil is higher and steeper than the curves for PAO and PAG lubricants, which are much lower and flatter.

Figure 3 shows PAO and PAG synthetic lubricants have similar trends for variation of EHL film thickness with temperature change. PAG lubricant gives thicker films than PAO lubricants at all temperatures. Mineral oil has a steeper curve of EHL film thickness versus temperature than PAO and PAG lubricants. At $T < 80°C$, mineral oil gives thicker films than PAO, and at $T < 57°C$ mineral oil gives thicker films than PAG lubricants. In the range $70 < T < 90°C$, there is only 5% difference between EHL film thickness of mineral and PAO lubricants. In this same temperature range, PAG lubricant gives thicker films ranging from 16% to 37% thicker than mineral oil.

CONCLUSIONS

1. PAO and PAG synthetic lubricants have similar trends for variation of EHL film thickness with temperature change. PAG lubricant gives thicker films than PAO lubricants at all temperatures.

2. Mineral oil has a steeper curve of EHL film thickness versus temperature than PAO and PAG lubricants. At $T < 80°C$, mineral oil gives thicker films than PAO, and at $T < 57°C$ mineral oil gives thicker films than PAG lubricants.

3. In the range $70 < T < 90°C$, there is only 5% difference between EHL film thickness of mineral and PAO lubricants. In this same temperature range, PAG lubricant gives thicker films ranging from 16% to 37% thicker than mineral oil.

REFERENCES

1. AGMA 925-A00, “Effect of Lubrication on Gear Surface Distress,” 2002.

Figure 1- Absolute viscosity

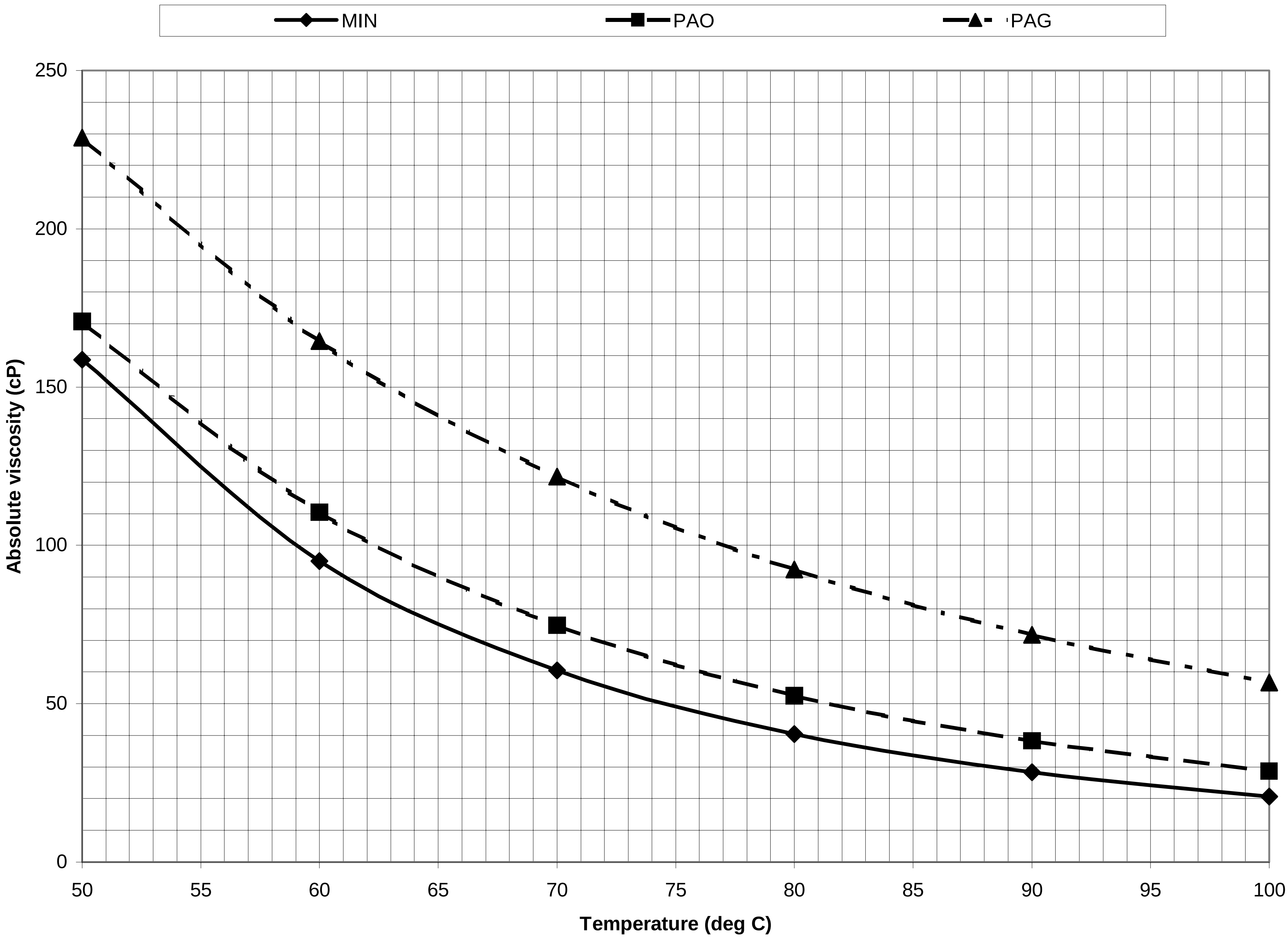

Figure 2- Pressure-viscosity coefficient

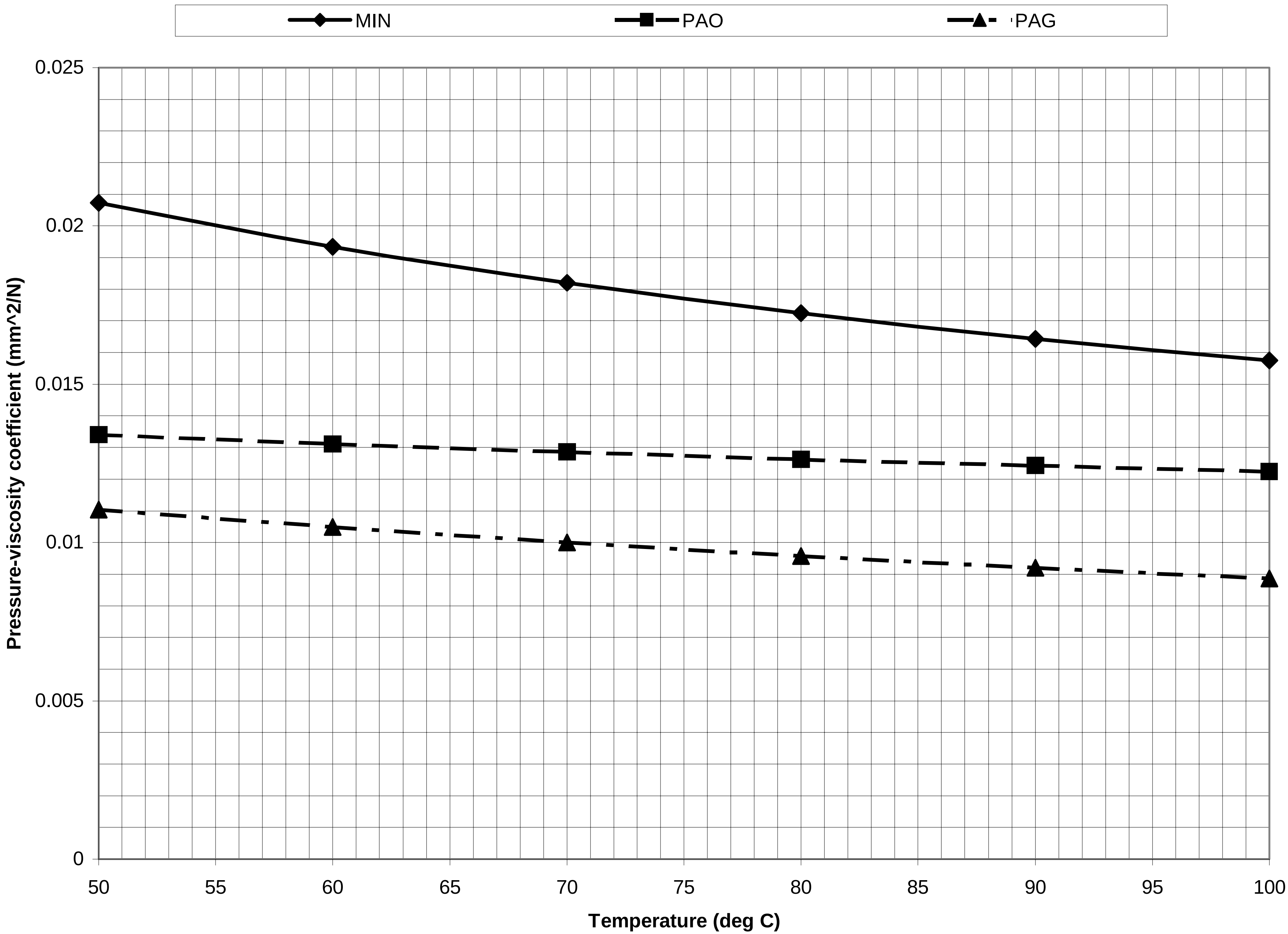

Figure 3- Relative EHL Film Thickness for Mineral, PAO, and PAG